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Tissue equivalence of brass mesh bolus and its efficacy in enhancing skin dose in the presence of skin–bolus air gaps

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ABSTRACT

Purpose: To evaluate the dosimetric performance and surface conformality of a commercially available brass mesh bolus (BMB) and compare with the clinically standard Superflab (SF) in realistic scenarios. Specifically, where air gaps and bolus rigidity often compromise surface dose, such as in post-mastectomy patients with tissue expanders.

Methods: Surface dose measurements were conducted using a PTW parallel plate chamber and Gafchromic EBT4 film on a breast phantom. Comparisons were made between BMB, SF, and solid water (SW) bolus materials. Treatment plans delivering 4005 cGy in 15 fractions were created in RayStation for 3D conformal radiation therapy (3D-CRT) and volumetric-modulated arc therapy (VMAT). Dose was evaluated at six BB-marked locations across the breast phantom using film dosimetry and compared with RayStation-calculated doses with a 3 mm virtual bolus.

Results: Ion chamber measurements under en face beams showed surface dose agreement to within 2.8% across SW, SF, and BMB. Film-based dose measurements revealed that while BMB and SF measurements agreed within 15% at all points, BMB yielded more consistent surface doses in regions where SF exhibited air gaps. In VMAT plans, BMB provided an average of 3% higher surface dose compared to SF. BMB also demonstrated improved conformality over SF, particularly in inferior and medial regions.

Conclusion: BMB provides comparable surface dose enhancement to SF in both 3D-CRT and VMAT while significantly improving conformity on irregular surfaces. These findings support the clinical use of BMB as a practical alternative to SF in scenarios where air gaps may compromise consistent surface dose delivery.

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INTRODUCTION

Bolus materials are applied to the patient's surface to increase the surface dose. Commonly used bolus materials, such as Superflab (SF), are tissue-equivalent with some flexibility, but may not conform uniformly to irregular surfaces, leading to the formation of air gaps that reduce the intended dose at the skin interface (Figure 1)[1,2]. Air gaps between bolus and skin are particularly common in patients with tissue expanders, where rigid implant geometry, combined with an irregular surface and daily setup variability, frequently prevent consistent bolus–skin contact. Prior studies have demonstrated that even small air gaps (<10mm) can significantly reduce surface dose for megavoltage photon beams by up to 10%. [2]. An alternative to improve dose conformity at the skin surface is brass mesh bolus (BMB) [3,4]. Brass mesh has been used in both electron and photon radiation therapy treatments to enhance skin dose while maintaining reproducibility [5].

The purpose of this study was twofold: (1) to evaluate the dosimetric equivalence of a commercially available brass mesh bolus relative to SF under en face conditions, and (2) to assess the impact of bolus conformality on surface dose for 3D Conformal Radiation Therapy (3D-CRT) and Volumetric Modulated Arc Therapy (VMAT) breast radiotherapy in clinically realistic scenarios where air-gaps are expected to be of concern

METHODS AND MATERIALS

A commercially available brass mesh bolus (BMB) from Radiation Products Design, Inc .was evaluated. According to vendor specifications, the material is composed of a copper alloy (93.75% Copper, 6% Tin, 0.25% Zinc) with a density ranging from 8.4 to 8.73 g/cm³. The stock mesh thickness is 0.18 mm, and the overall panel thickness 1.5 mm due to its hollow mesh structure. The vendor-reported tissue-equivalent thickness ranges between 2.0 and 3.0 mm . In this study, the dosimetric performance was compared to Superflab bolus (clinical standard) of comparable tissue equivalent thickness (3mm).

To determine the dosimetric tissue equivalence of the BMB, surface dose measurements were performed. A calibrated PTW TN34045 parallel-plate ionization chamber was placed inside a solid water slab with a chamber-specific cutout with an additional 5 cm solid water underneath for backscatter. The chamber was centered in a 10 × 10 cm² 6 MV photon field utilizing a on a Varian Truebeam linear accelerator. Measurements were acquired with either SW (2, 3, 5 or 15mm), SF (3 or 5mm), or BMB (single and double layer) placed directly on the chamber entrance window at a 100 cm source-to-surface distance with a 10 × 10 cm² 6 MV photon field. Using 200 MU for each irradiation, measurements were performed in triplicate and the fully corrected signal was normalized to the 15mm SW configuration to derive relative surface dose values.

Six positional (BB) markers were distributed across the medial–lateral and superior–inferior extents of the breast surface of a RANDO breast phantom to sample regions with and without expected bolus air gaps (Figure 2A–B). A single 6 MV VMAT and 3D-CRT treatment plan was generated in RayStation to deliver a prescribed dose of 4005 cGy in 15 fractions Figure 2C-2D). Each plan was delivered once using Superflab and once using brass mesh bolus, with bolus placement intentionally mimicking clinical setup, including minimal taping and allowance for natural draping (Figure 2E–F).

To determine surface dose, Gafchromic™ EBT4 film was used in this study 2 X 2 cm film squares were placed at the 6 BB-marked locations on the breast phantom to measure surface dose. To account for film non-uniformity, films were pre-scanned to establish baseline optical density and post-scanned 24 hours post-irradiation to allow for polymerization stabilization. All scanning was performed using an Epson Expression 10000XL flatbed scanner with consistent settings (48-bit RGB, 72 dpi, transmission mode, landscape orientation, without color correction).

A calibration curve was established by irradiating films to known doses ranging from 50 to 300 cGy using a 6MV photon beam under reference conditions (10x10cm² field size, 100cm source-to-surface distance, at the depth of maximum dose (15mm)) in a Solid Water® phantom Film analysis was performed using Fiji The red color channel was extracted for analysis due to its superior sensitivity in this dose range. The mean pixel intensity values (P) were converted to Net Optical Density (netOD) using the following relationship:

$$netOD = log_{10}\left(\frac{P_{unexposed}}{P_{exposed}}\right)$$

The average netOD within a 1 x 1 cm2 region of interest at the center of each film was then extracted (Figure 3B). The scanning workflow and resulting calibration curve are shown in Figure 3 .

Buildup	Reading (nC)	Dose (Gy)	TMR
15mm SW	1.42 E-09	2.04	1.00
2mm SW	1.01 E-09	1.45	0.71
3mm SW	***1.10 E-09***	***1.58***	***0.77***
5mm SW	1.25 E-09	1.880	0.88
3mm SF	***1.14 E-09***	***1.64***	***0.80***
5mm SF	1.27 E-09	1.83	0.89
1 BMB	0.96 E-10	1.38	0.68
2 BMB	***1.12 E-09***	***1.61***	***0.79***

Table 1: Relative surface dose measurements under enface conditions using a 6 MV normalized to 1.5 cm solid water (SW). Measurements were performed using a PTW parallel-plate ionization chamber (N=1.44 E+0.9) at 100 cm SSD with a 10 × 10 cm² field. Comparable buildup configurations relative to 0.3 cm Superflab (SF) are highlighted in yellow.

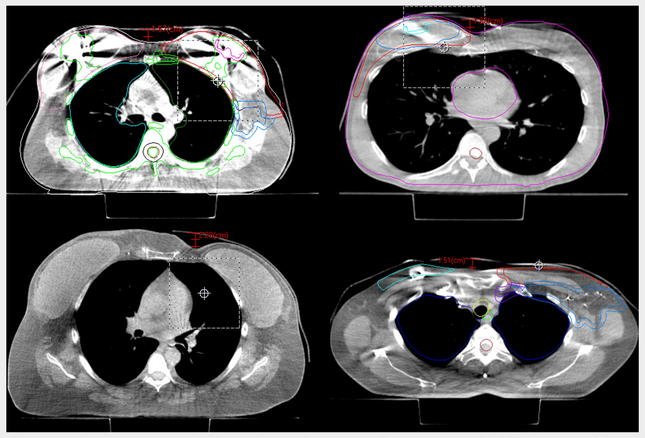

Figure 1: Representative kV Cone Beam Computed Tomography (CBCT) images of four patients illustrating the lack of conformity of Superflab when treating patients with tissue expanders. The max air gaps were 16mm (top left), 17mm (top right), 23mm (bottom left), and 15mm (bottom right)

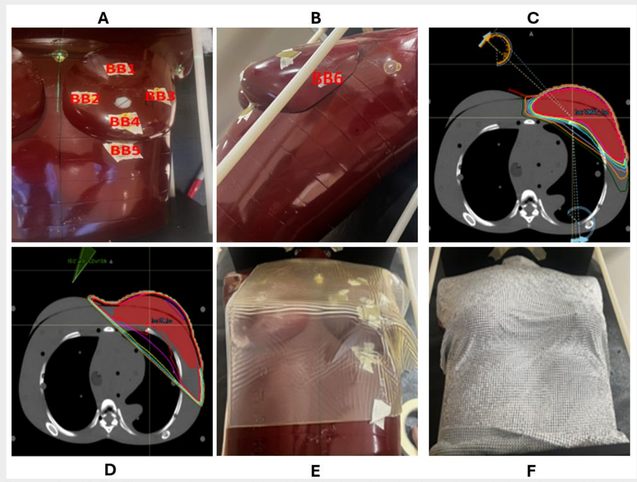

Figure 2 : (A,B) The phantom used in this study with the location of the six positional (BB) markers 6 BB's, and corresponding film, demarcated. An axial view of the VMAT (C) and 3DCRT (D) plans used in this study. Superflab (E) and brass mesh bolus (F) placement on the phantom for measurements

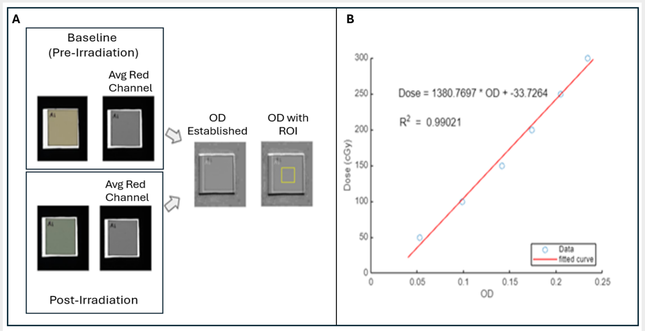

Figure 3: (A) Schematic of the analysis pipeline. Films were scanned pre-irradiation and 24 hours post-irradiation. The red color channel was extracted from both images to calculate Net Optical Density (NetOD) within the defined Region of Interest (ROI). (B) Calibration curve established in Solid Water. The plot illustrates the linear relationship between measured NetOD and absorbed dose (cGy) over the range of 50–300 cGy

RESULTS

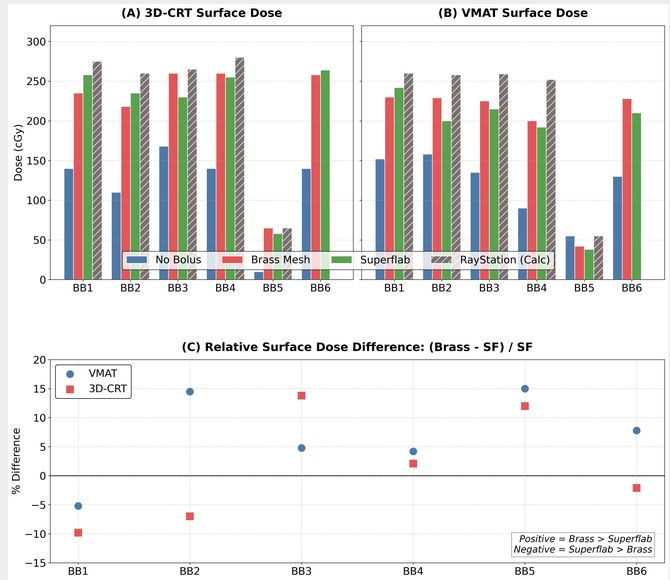

Figure 4. Comparison of measured calculated surface doses across anatomical locations (BB1–BB6). (A–B) Surface dose (cGy) measured for (A) 3D-CRT and (B) VMAT treatment techniques. Bar clusters represent measured doses for No Bolus (blue), Brass Mesh (red), and Superflab (green), alongside Treatment Planning System (RayStation) calculated dose (hatched gray). (C) Relative percent difference in surface dose between Brass Mesh and Superflab measurements, calculated $[(D_{Brass}-D_{SF})/D_{SF}]$. Data points above the zero line indicate locations where Brass Mesh resulted in a higher surface dose than Superflab, while points below indicate higher doses with Superflab

Relative surface dose measurements under en face irradiation demonstrated agreement within 2.8% among SW, SF, and BMB , indicating similar buildup characteristics under ideal contact conditions (Table 1). This narrow range of agreement highlights the difficulty of determining water-equivalent thickness using transmission-based measurements alone, given the competing effects of material density and electron backscatter.

Film-based surface dose measurements for 6MV VMAT and 3D-CRT plans are summarized in Figure 4. Six BB-marked surface locations (BB1–BB6) were analyzed to sample regions spanning the full medial–lateral and superior–inferior extent of the breast phantom, including locations with full bolus contact and locations with clinically relevant air gaps.

For 3D-CRT delivery, the corresponding average surface doses across BBs 1–4 were 139.2 cGy without bolus, 243.5 cGy with BMB, and 244.5 cGy with SF, compared with a calculated dose of 269.6 cGy. At BBs where full bolus contact was achieved (BB1 and BB4), Superflab produced slightly higher surface dose than BMB. At BBs with partial contact or air gaps, the two bolus materials demonstrated comparable performance.

For VMAT delivery, the average measured surface dose across BBs 1–4 was 133.7 cGy without bolus, 221.7 cGy with BMB, and 213.1 cGy with SF, compared with a RayStation-calculated surface dose of 258.5 cGy using a virtual 3 mm bolus. Brass mesh bolus yielded consistently higher surface dose than Superflab at BBs affected by air gaps, with an average increase of approximately 3%.

Across all measurement points and both treatment techniques, BMB and SF surface doses agreed to within 15%. The largest absolute difference observed was 33 cGy at BB3 for 3D-CRT delivery, which remains within clinically acceptable surface dose variability. BB5 consistently received lower dose due to partial field coverage at the inferior edge of the treatment field.

CONCLUSIONS

Brass mesh bolus and Superflab provide comparable surface dose for breast radiotherapy using both 3D-CRT and VMAT techniques. In the presence of air gaps, brass mesh bolus demonstrates improved conformality and slightly higher surface dose consistency. For clinical scenarios in which achieving uniform bolus–skin contact is challenging, such as in patients with tissue expanders, brass mesh bolus represents a robust and practical alternative

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